REAL AND SIMULATED CRASHWORTHINESS TESTS ON BUSES

VINCZE-PAP Sándor
AUTÓKUT, Budapest
Hungary
CSISZÁR András
EDAG Hungary Ltd., Győr
Hungary

ID: 05-0233

ABSTRACT

This paper discusses the design aspects of bus frontal impact behavior as one of the main subjects of bus crashworthiness and surveys conditions and results of previous full impact laboratory tests comparing the FEM simulation results carried out on a Hungarian Ikarus bus.

Clarifying the adequate background gives possibilities for checking bus passive safety solutions by computer and the best utilizable resolutions can be applied in the standardized production. This paper shows frontal impact test arrangements of a 10 tons' city bus with three different impact speeds and computer simulation versions of these real tests. It gives possibilities to compare the test results to the requirements of current bus regulations.

BUS CRASHWORTHINESS – FRONTAL IMPACT

Design for frontal impact, side impact and rollover safety come within the crashworthiness subject.

Frontal impact of automobiles is an accurately researched and well-circled topic versus bus frontal impact behavior.

A well-designed bus structure has good deformation and energy absorbing capability. In case of frontal impact it has to meet three criteria:

Force criterion: the order of stability loosing (crushing) of structural elements happens in pre-determined sequence; the forces due to the plastic hinges are in successive magnitude;

Energy criterion: the kinetic energy of the vehicle must be absorbed with deformation energy of other pre-determined elements of bus framework to avoid the damage of any protected structural element (initial condition for generating the safety bumper features)

Kinematical deformation criterion: during the energy absorbing process the (elastic and residual) displacement possibility of structural elements is limited and the damage-free conditions of elements can be allowed or ensured due to this.

The reality of above-mentioned goals was investigated by a test series carried out at AUTÓKUT in 80's. Dynamic impact tests on full-scale bus, driver space, front-wall, understructure, bumper and bumper elements were accomplished.

All kinds of crashworthiness' demand claims to minimize the injury probability of vehicle driver and passengers during standard accident conditions or to maximize their survival chance.

According to the knowledge of biomechanical tolerance limits of human beings two basic premises shall be fulfilled:

- As rigid as possible driver and passenger zones shall be created for ensuring the so-called "survival space";
- Suitable energy absorbing zones shall be designed for limiting the (inertia forces) acting on the drivers and passengers for reducing the inner impact forces, which can cause fatality.

„Survival zone" of bus is defined only for rollover safety (ECE R66) and regards to the passenger area exclusively, but it is not adaptable to the frontal impact due to the primacy of driver cabin. Ensuring to keep in a prescribed space and cover the surroundings with energy absorbing materials are the two most effective tools for mitigation of injury risk of passengers (and partly of the driver). [1]

Deformations and displacements of certain vehicle equipment, accessories (dashboard, steering-wheel, seat-back,) shall not cause the dangerous reduction of „personal free space".

Structural behavior of bumper, understructure, front-wall, driver seat anchorages, passenger seat structural strength and fixing are giving the main tasks at structural strength design.

On the analogy of automobile, the bus energy absorbing capability of a bus can be defined as follows: aim is to create such an understructure with adapted bumper which can absorb the bus impact energy by crushing of bumper elements and elastic compression of understructure due to min. 7 km/h impact into rigid wall. In this case the impact energy to be absorbed is 19 kJ for a 10-ton bus. **[2]** (The calculated impact energy is 25 kJ at 8 km/h impact speed.)

REAL IMPACT TESTS [2] [3]

Full impact onto rigid wall

Ikarus 411 type bus was the test vehicle (prototype of the current running IK 415 city buses). The rigid wall was a 300 tons concrete block with wooden surface in 50 mm thickness. There were 4 load transducers between the impact surface and the concrete block. Opto-gate measured the impact speed. In the passenger cabin two 50 % male dummy (Hybrid II and Ogle) were seated and the Hybrid II dummy was equipped with head and chest accelerometers and femur load transducers in the right leg. A longitudinal accelerometer was fixed onto the floor above the CGV of the bus.

The test bus was impacted three times with three different speeds. **[3]**

Vehicle dimensions:
Length: 11000 mm
Width: 2500 mm
Height: 2940 mm
Axle distance: 5570 mm
Front/rear overhang: 2630/2800 mm

Measured values	**Bus frontal impact onto rigid wall**		
	3,6 km/h speed	**6,98 km/h speed**	**29,76 km/h speed**
Max. impact force at the left longitudinal beam [kN]	180	220	780
Max. impact force at the right longitudinal beam [kN]	160	190	390
Resultant impact force [kN]	320	390	1100
Max. acceleration on the floor above the CGV [g]	3	4	12
Max. resultant acceleration in the Hybrid II head [g]	3	10	60
Measured max. femur force in the Hybrid II dummy [kN]	1,1	1,3	1,6

Table 1. Results of three frontal impacts

(The IK 411 bus was equipped with the same bumper as was developed for the IK 250 type bus, **Fig. 1.a**.) The mass of bus prepared for test was: 10 080 kg.
There was only elastic deformation at the first (3,6 km/h) impact, and there was no outer damage on the bus after the second (6,98 km/h) impact test. The detailed examination discovered the crushing destruction at left side; the bumper connecting tubes (two 60/40x2 mm tubes between the bumper surface and the longitudinal beam) have crumpled. (**Fig. 1.b-c.)**

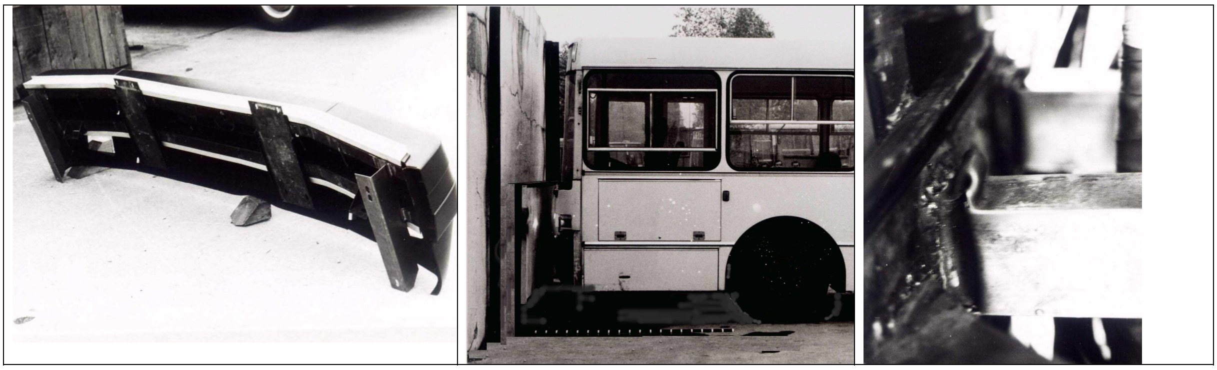


Figure 1a-c. Pictures on the bumper and bus frontal impact test with 6,98 km/h speed

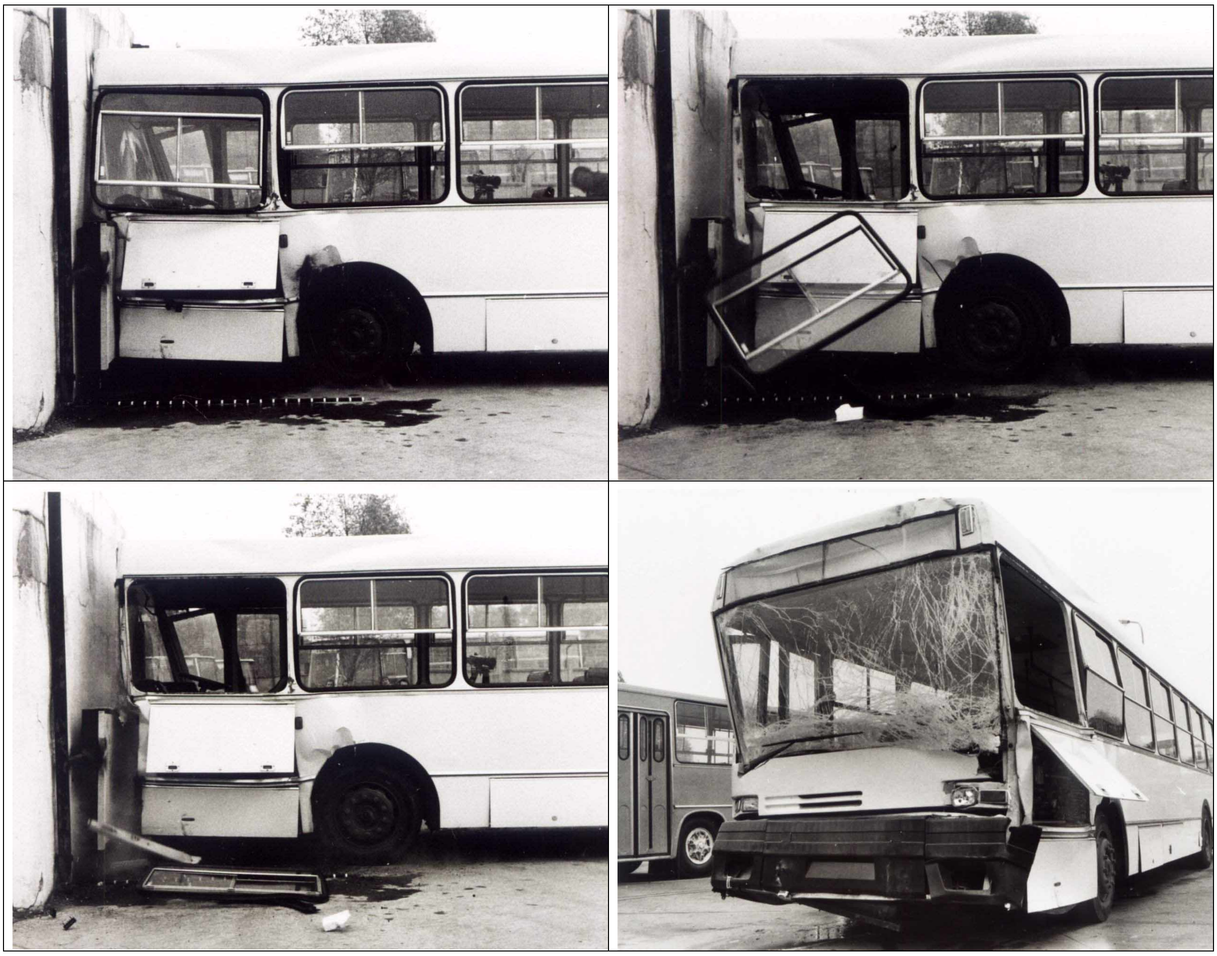


Figure 2a-d. Phases of frontal impact with 29,76 km/h speed; the front-wall wrinkled up onto the wooden impact surface which measured distance was 250 mm from the concrete block and the roof's edge reached the block too.

The left beam has suffered significant deformation after the 29,76 km/h speed impact; 130 mm was the measured specific compression. (**Fig. 3.a.**) On the right beam the measured compression was less, only 80 mm. (The left side is less rigid as the right one due to the left-side front door-frame.) The driver seat has slid back thanks to the driver safety platform and the dashboard has cracked. The free distance between the steering wheel and the frontal surface of driver seatback was 330 mm, which ensures the survival due to the safety platform. (**Fig. 3.b-c.**)

Figure 3a-c. Consequences of the 29,76 km/h speed impact

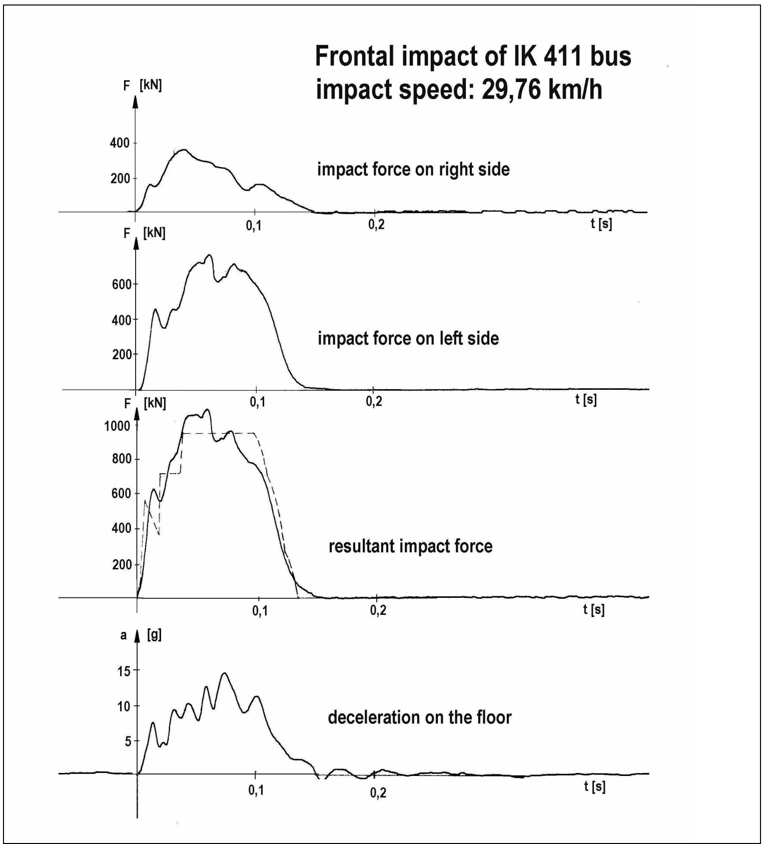


Figure 4. Force and acceleration diagrams of 29,76 km/h speed frontal impact

The rigidities of right and left side of bus are significantly different, the measured impact force is doubled on the right side as the left one. At 30 km/h speed impact the observed floor deceleration is little bit higher than the prescribed value of ECE R80. The standardized average value shall be between 8-12 g related to the regulation of ECE 80, which is determined for testing of bus seat-frame strength and fixing.

The next statements can be made if the result is evaluated according to the criteria of force, energy and metamorphosis:

The bumper elements shall have less rigidity than the chassis itself by the ***criterion of force***. This became untrue at 7 km/h speed impact, the chassis would have been stiffened. (This reinforcing was performed during the serial modification of IK 415 buses.)

By the supposed ***energy criterion*** the kinetic energy of the vehicle must be absorbed by elastic deformation energy of other pre-determined elements of bus bumper and framework up to 3,5 km/h impact. Over this speed (up to 8 km/h impact speed in optimum) only the changeable elements of bumper can be destroyed.

This bus did not fulfill this presupposition due to the crumpling of understructure at 7 km/h impact.

By the ***deformation criterion*** during the energy absorbing process the (elastic and residual) displacement possibility of structural elements shall be limited and the deformation order of structural elements shall be in presupposed way. The damage-free conditions of elements can be allowed or ensured due to this. It was fulfilled.

Bus front-wall (driver cabin) tests

The so-called safety platform serves the ensuring suitable and adequate survival space (free space between the dashboard, steering wheel and driver seat) for the bus driver during and after crash process. It was experimented on development of IK 200 buses and applied in final serial models.

Different types of static and pendulum impact tests were carried out to clarify the mechanism of safety platform. (**Figures 5, 6**.)

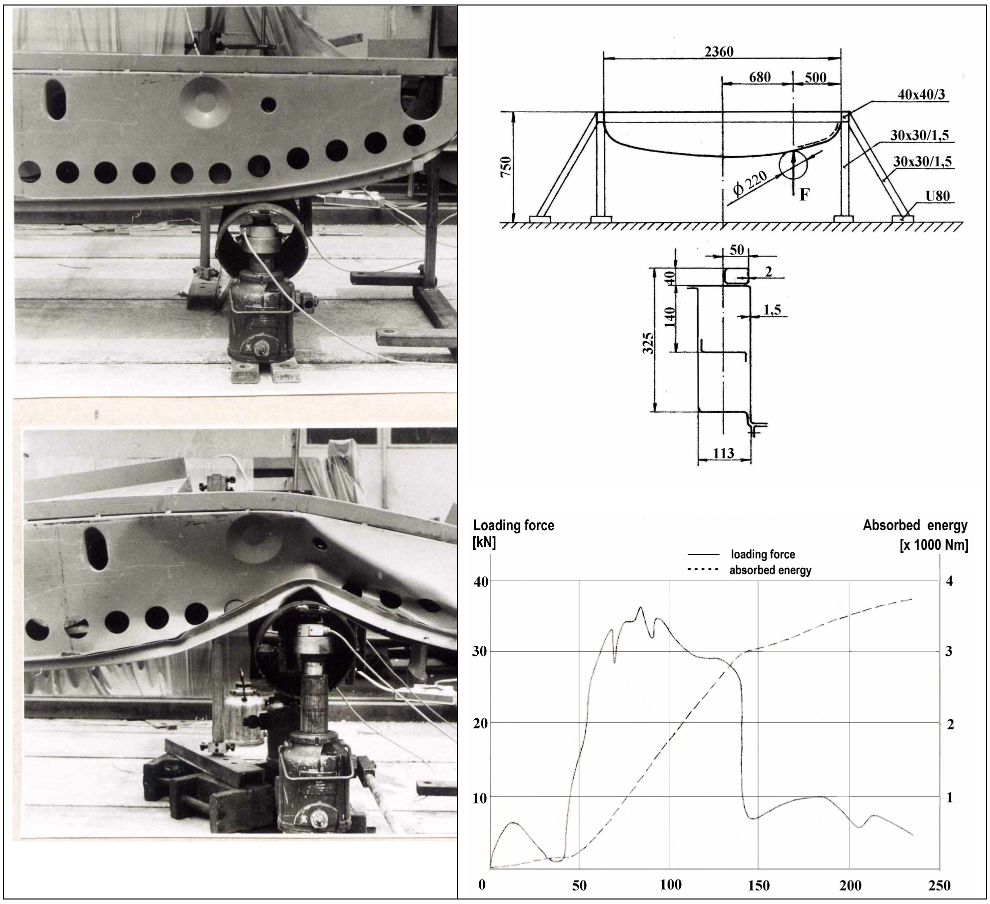
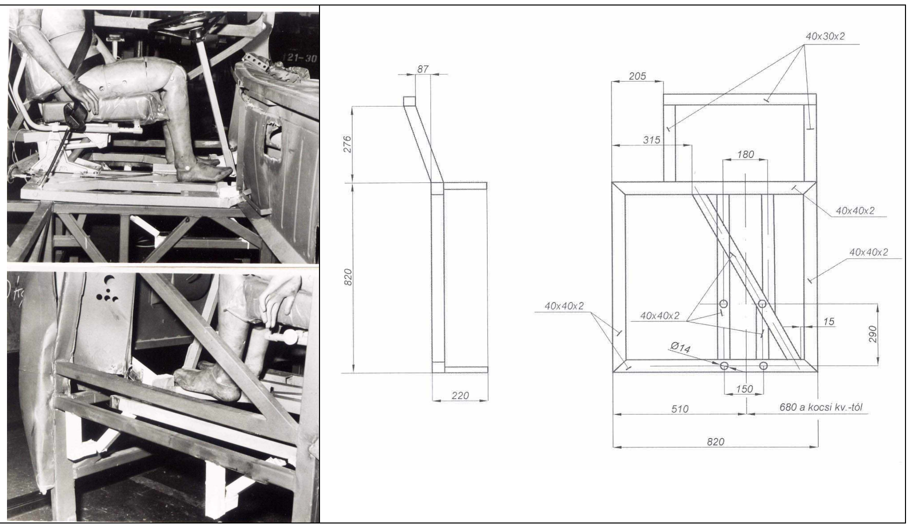


Figure 5. Static energy absorbing test of front-wall rail (in case of impact with a tree)

Figure 6. Pendulum impact test of driver cabin with safety platform; working mechanism and sketch of driver safety platform



Static and dynamic test of IK 411 understructure [3]

Quasi-static laboratory compression test was carried out on the IK 411 K1 understructure and the force demand for the first plastic joint was measured in value of 305 kN. Newly tested after modification, reinforcement, the measured maximum compression force was 400 kN.

Two pendulum tests happened on this understructure with a 4.1 ton-pendulum from two different heights. By an impact with E_1=16 kJ energy only slight deformations occurred, then four plastic joints were detected after impact with E_2=18,5 kJ energy, the understructure crumpled. (**Figure 7.**)

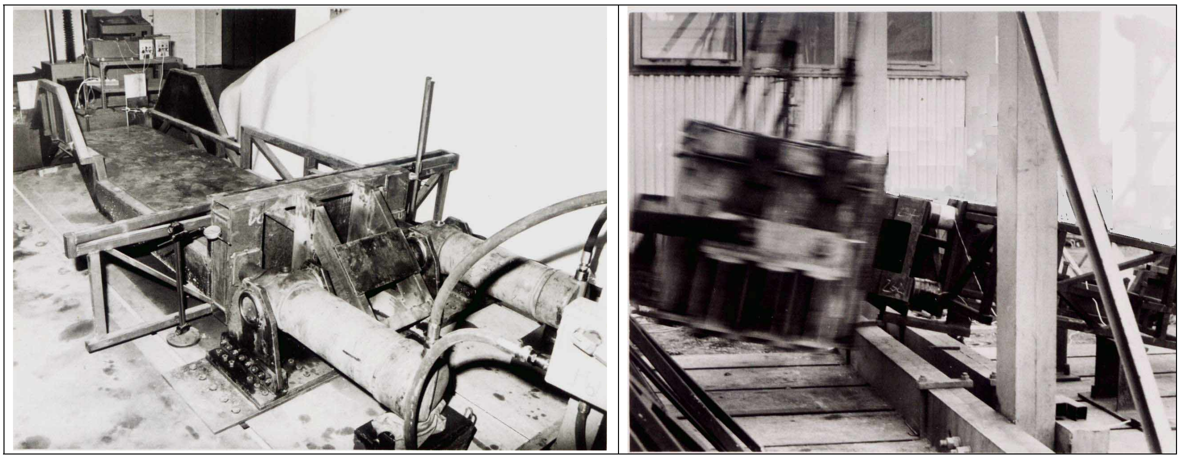


Figure 7. Static and dynamic tests of bus understructure

Static test of inner elements of IK 411 bus

Energy absorbing elements of IK 411 bus bumper were designed from 4 pieces of 60/40x2 mm cross-section rectangular tubes with length of 175 mm. The maximum force due to stability limit of four inner elements was 580 kN, which force was decreased to 380 kN after 100 mm displacement. The crushed tubes were deformed not only in longitudinal direction, but buckled too due to the oblique connection. Maximum resultant compression of inner elements was 115 mm. (The yield stress of mild steel bumper elements was 240 MPa.) The bumper is able to suffer 240 mm of accumulated compression. (**Figure 8**.)

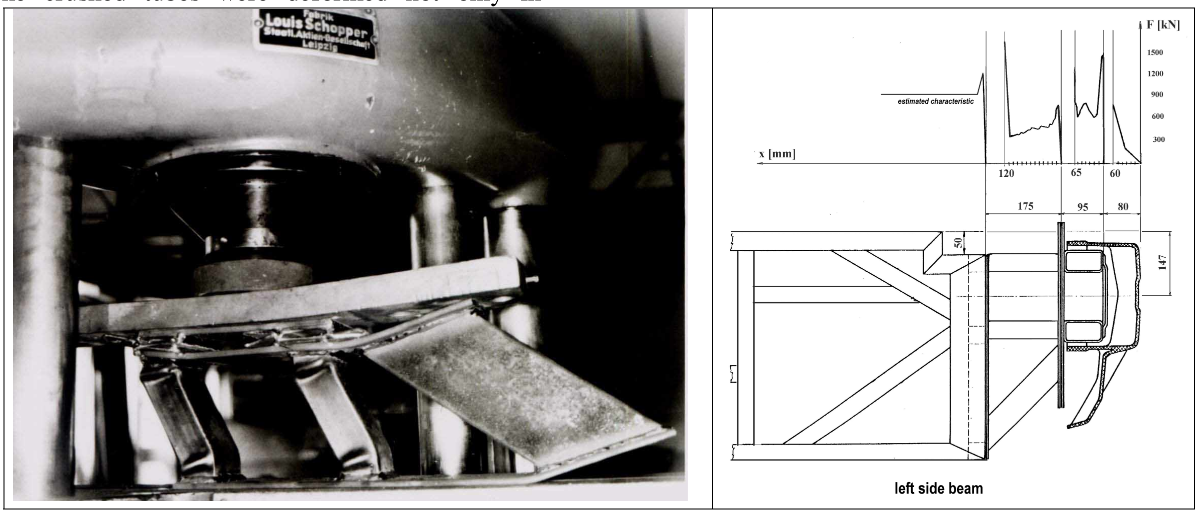


Figure 8. Static compression test of bumper energy absorbing elements of IK 411 bus

FEM SIMULATIONS

Simulation model [5]

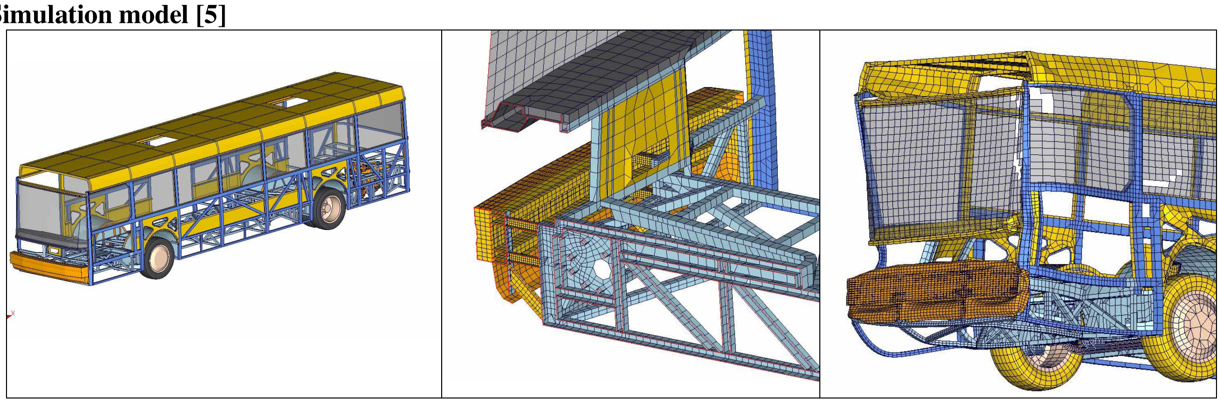


Figure 9. Elastic material properties for glazing with rupturing are defined by max. plastic strain

The bus model in the used PAMCRASH program is structured by sheet elements. The layout of front and rear axles, engine-gearbox connections to the frame-structure happened with joint-balled bar elements.

Dynamic Crash analysis has been performed on the FEA model detailed below:

Analysis type: Front Crash, impacting into rigid wall under three load cases as initial velocity (3,6km/h, 6,98 and 29,76 km/h)

FEA model: Number of Element: 79091 (SHELL) - Number of Nodes: 71432 – Number of properties: 98

Total model mass: 10007 kg

Bumper: The Bumper structure as energy absorbing part was composed of three major components.

a) Covering plastic shell

b) Foam (polyurethane) *(applied stress-strain curve in **Fig. 11**)*

c) Steel tubes *(applied stress-strain curve in **Fig. 10**)*

Material type: Elastic-plastic material properties with strain rate dependent hardening for steel parts. Elastic material properties for glazing with rupturing is defined by max. plastic strain. ***(Fig. 9)***

FEA Solver: PamCrash v.2001

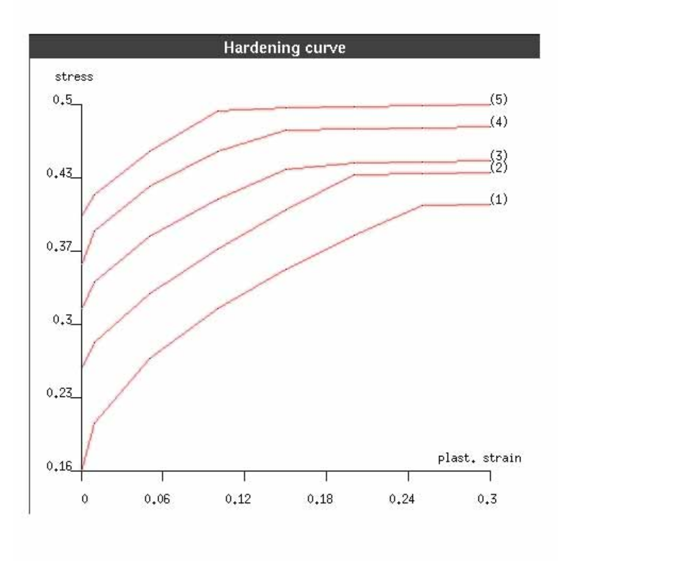


Figure 10. Applied stress-strain curve of steel tubes

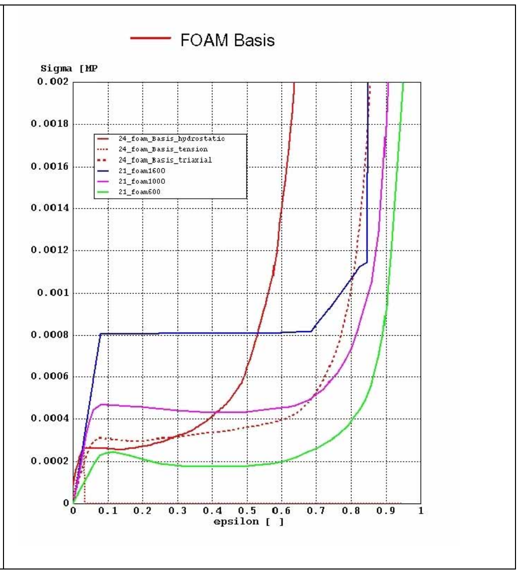
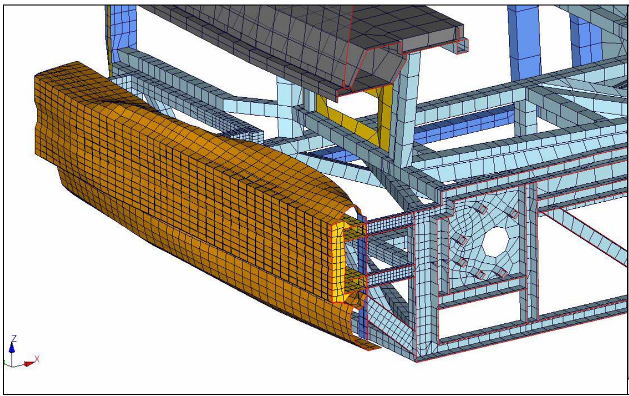
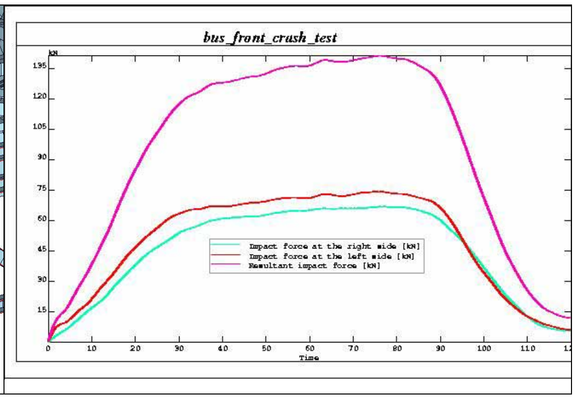


Figure 11. Polyurethane applied stress-strain curve

Impact simulation test with 3,6 km/h speed





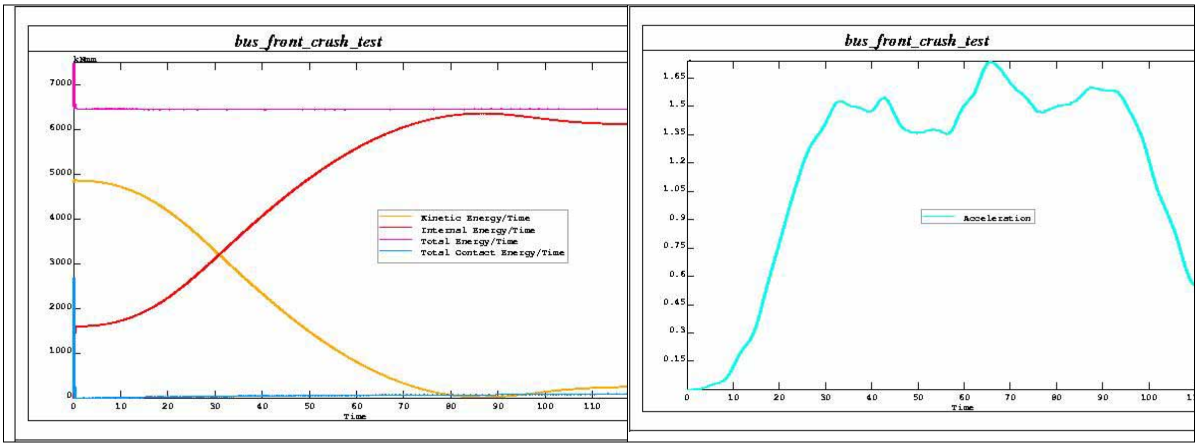


Figure 12. Elastically deformed bumper at the 3,6 km test [maximum deformation](a); the [left, right and resultant] force curves (b); energy diagrams (c); deceleration on the floor at CG in [g] (d)

Impact simulation test with 6,98 km/h speed

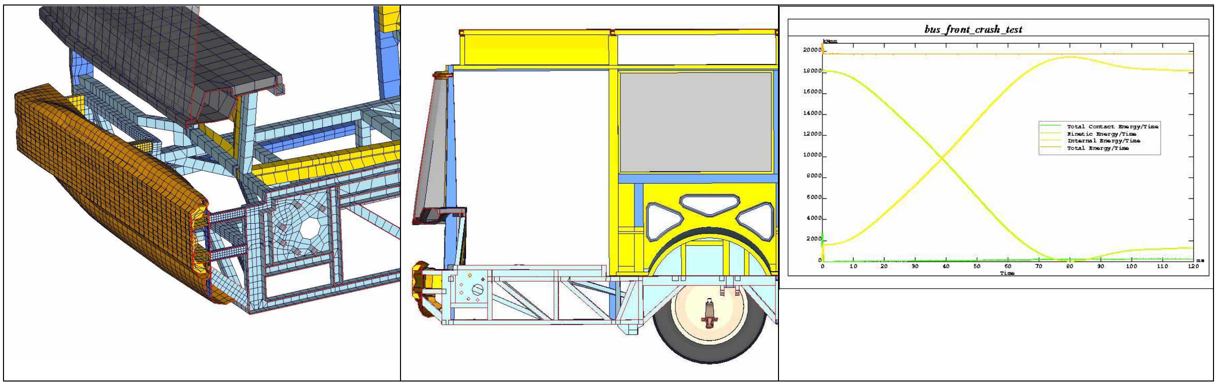


Figure 13. Deformed energy absorbing elements of bumper at the 6,98 km test (a,b); energy diagrams (c)

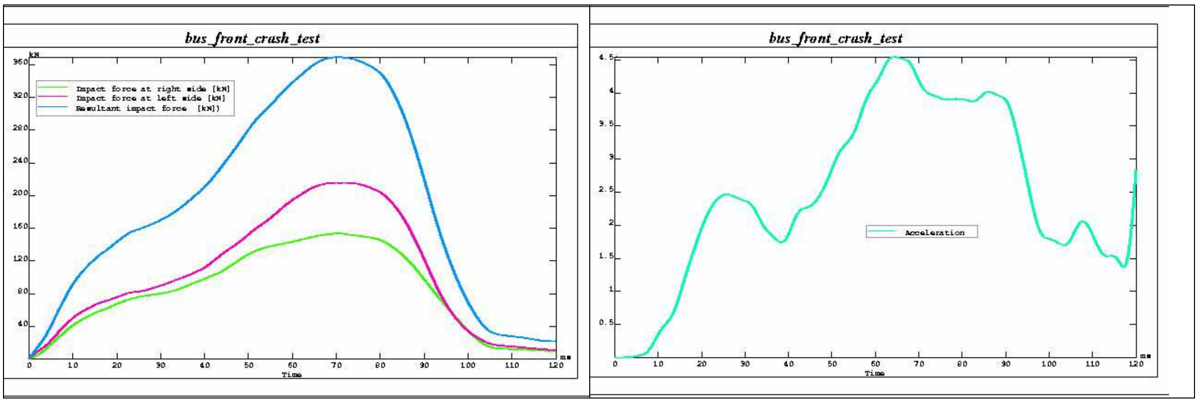


Figure 14. The [left, right and resultant] force curves at the 6,98 km test (a); deceleration on the floor at CG in [g] (b)

Impact simulation test with 29,76 km/h speed

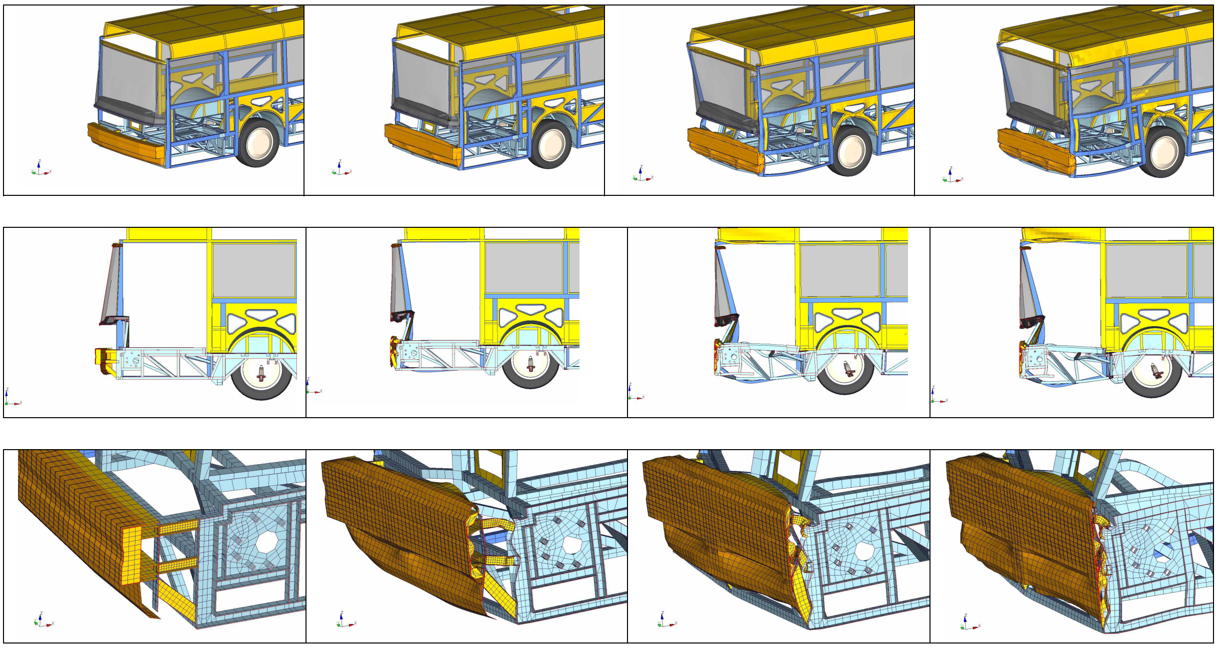


Figure 15. Some pictures on deformation process at 29.76 km/h speed impact

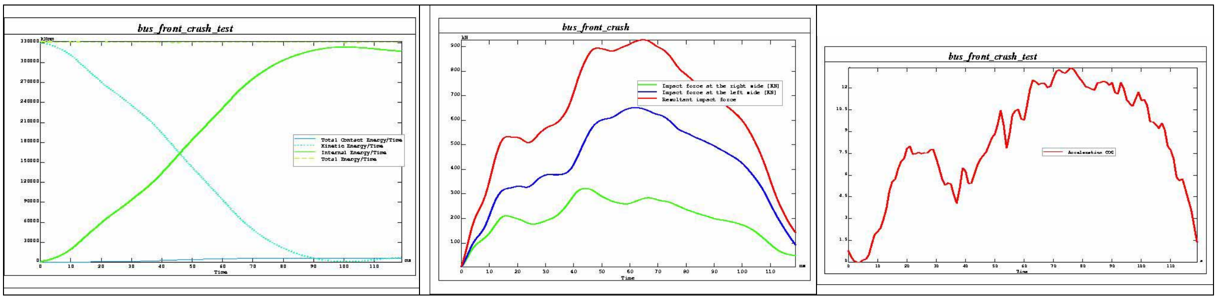


Figure 16. Energy diagram curves at the 29,76 km test (a;) the [left, right and resultant] force (b); deceleration on the floor at CG in [g] (c)

CONCLUSIONS

At full test with 29,76 km/h speed the measured floor deceleration is a bit higher than with prescribed trolley deceleration by ECE R80. (ECE R80 prescribes 8-12 g deceleration for trolley at 30 km/h speed standardized impact. The measured values are rather congruent with the force (rooted from 11-13 g deceleration) required by ECE R14 related to M3 bus category seat-belt anchorages. [4]

The front-wall, understructure, bumper energy-absorbing capability shall be examined together and shall be linked them due to the force, energy and kinematical deformation criteria.

The detailed and accurate FEM model simulation has lead to analogous result as real impact test. (**Fig. 17.**)

This developed model set-up and simulation version is very effective tool for checking the bus impact behavior in the design process.

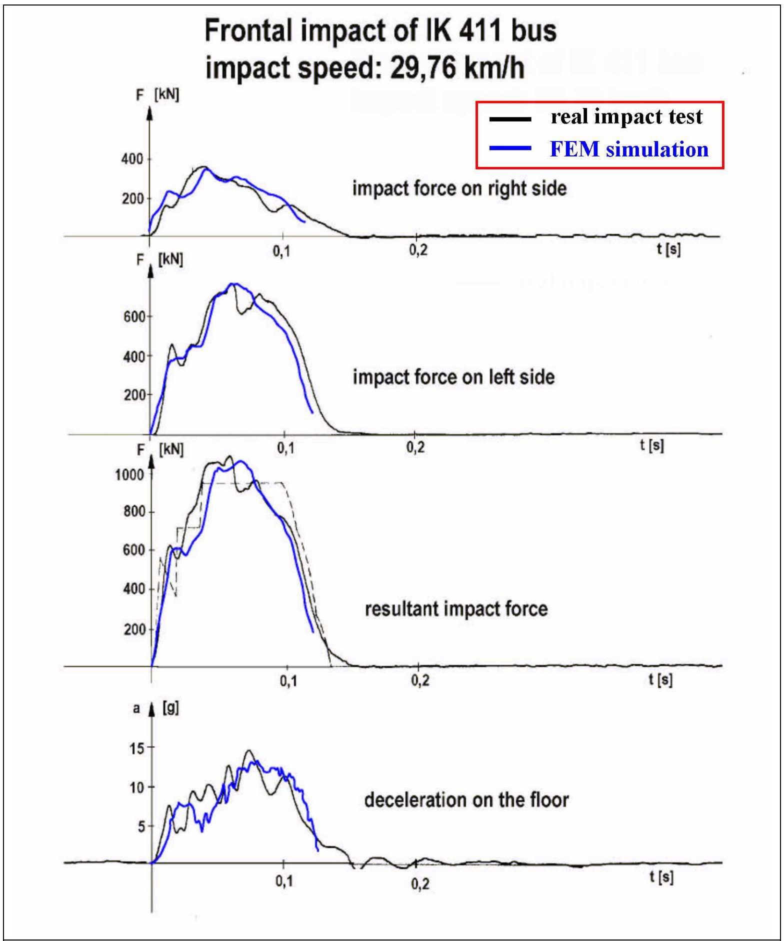


Figure 17.
Interlocking the real and simulation impact test results. The measured and calculated curves are well congruent.

REFERENCES

[1] *S. Vincze-Pap*: Tests evaluation on passive safety requirements for bus driver cabin (AUTÓKUT Test Report, JÁ-244/80/14–1980)

[2] *L. Albrecht*: Front-wall test of IK 411 K1 bus (AUTÓKUT Test Report, AU-53/85 –1985)

[3] *S. Vincze-Pap*: Stability tests on understructure of IK 400 bus (AUTÓKUT Test Report, JÁ-244/80/21–1980)

[4] ECE Regulation 80: Uniform provisions concerning the approval of seats of large passenger vehicles and of these vehicles with regard to the strength of the seats and their anchorages, 07/2001

[5] *S. Vincze-Pap, N. Horváth, A. Csiszár, A. Szász*: Autóbuszok passzív biztonsági vizsgálata számítógéppel *(Bus passive safety tests with computer),* Paper No.: 308 on the CD, ISBN 963 9058 17 3, 33rd Meeting of bus and coach experts, 2-4 September, 2002, Keszthely, Hungary